RETRIEVAL OF LEAF AREA INDEX BY INVERTING HYPER-SPECTRAL, MULTI-ANGULAR CHRIS/PROBA DATA FROM SPARC 2003

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ABSTRACT

The SPARC campaign has been organized in coincidence of CHRIS/Proba multi-angular and hyper-spectral acquisition over the agricultural test site of Barrax in Spain. Radiometric and biophysical vegetation parameters measurements have been carried out for different crops in both field and laboratory.

The aim of this preliminary study is to assess the capability to estimate Leaf Area Index (LAI) from CHRIS/Proba data by inverting the coupled radiative transfer models PROSPECT+SAILH. Two different approaches have been used to invert canopy reflectance observed in 5 directions and 62 spectral bands: Look Up Tables and Pest ASP Tool.

Results show that the use of a priori knowledge is of great importance for the estimation of LAI. In this way we have been able to estimate this parameter with an accuracy of around 15%÷20% for Alfalfa, Potatoes, and Sugar Beet samples.

1. INTRODUCTION

Over the past decade, there has been a great interest in the application of Earth Observation techniques in the field of hydrology, water management and precision farming [1].

More in particular, hydrological models for the simulation of water flow in the soil-vegetation-atmosphere system require the estimation of canopy parameters such as LAI, surface albedo, and crop height [2].

D'Urso et al.[3] have exploited remote sensing data to estimate these canopy characteristics by using empirical approaches based on spectral indices. These approaches are based on simplified assumptions on the reflective behavior of vegetation thus limiting the resulting accuracy in absence of a proper calibration of the empirical relationship adopted. On the other hand, it has been shown that the estimation of canopy characteristics can be improved and generalized if spectral directional information is available [4], [5].

The Compact High Resolution Imaging Spectrometer on board the Proba platform (http://www.chris-proba.org.uk/) has made available hyper-spectral and multi-angular high resolution observations from space on selected sites during 2003. This mission was considered as an unique opportunity to validate radiative transfer models of vegetation from satellite, in order to assess the accuracy of these models in the estimation of the canopy characteristics of our interests.

In this preliminary research work, we have used CHRIS/Proba data acquired over the agricultural site of Barrax (Spain) in conjunction with the radiative transfer models PROSPECT (leaf level) [13] and SAILH (canopy model) [9]. The reflectance models were applied in the inverse mode to retrieve the value of Leaf Area Index for different crops in the test-site.

Two inversion techniques were applied, the first based on LookUp tables and the second on a non-linear parameter estimation software.

2. DATA AND METHODOLOGY

2.1 Study Area

The SPARC campaign was carried out in Barrax (N30°3', W2°6'), an agriculture test area situated within La Mancha region in the south of Spain, from 12 to 14 July 2003.

The area has been analysed for agricultural research for many years thanks to its flat topography (differences in elevation range up to 2 m only) and its large, uniform stands of Alfalfa, Corn, Sugar Beet, Onions, Garlic and Potatoes. Around 35% of the area is irrigated while the remaining 65% is dry land (Fig. 1).

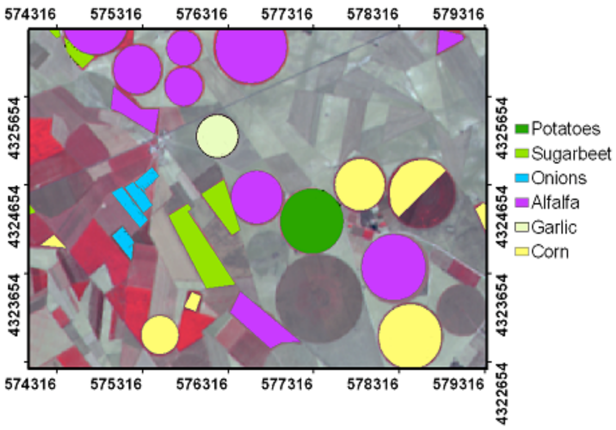

Fig. 1. Agricultural land use in Barrax test site

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During the SPARC campaign, different sensors were flown in this time interval, with resolution ranging from 1 m (airborne Rosis operated by DLR) to 300 m (MERIS on Envisat).

2.2 CHRIS Data Acquisitions

CHRIS/Proba hyper-spectral, multi-angular imagery was collected on 12 and 14 July 2003 with overpass times 11:07 and 11:32 (UT) respectively (Table 1).

Five images with different nominal view angles (-55º, -36º, 0º, +36º, +55º along-track zenith angles) and 62 spectral bands (from 410 nm to 1050 nm) per angle were acquired for each pass. The covered image area is 14 km x 14 km (748 X 748 pixels) with a spatial resolution of 36 m (Table 2).

Fig.2 shows the angular sampling of CHRIS/Proba image acquisition over Barrax site. The images were atmospherically corrected at the University of Valencia by mean of an improved algorithm based on Vermote et al. scheme for MODIS atmospheric correction [6].

2.3 Field and Lab Measurements

Extensive and systematic in situ measurements included spectral calibration data and determination of main biophysical parameters [7].

Field non-destructive measurements of Leaf Area Index (LAI) and Mean Tilt Angle (MTA) were made by means of the digital analyser Licor LAI-2000; leaf chlorophyll content was measured with the CCM-200 Chlorophyll Content Meter. A set of 39 out of 113 LAI measurements was included on the overlap area of multi-angular CHRIS/Proba images and this set was used for this preliminary study. Measurements of LAI and leaf chlorophyll content were carried out again in the laboratory from destructive samples in order to validate those taken in situ by the CCM-200 showing a good correlation between the two data sets [8]. Additional measurements on leaf water content and leaf dry matter were also taken.

In addition to the LAI and chlorophyll, radiometric measurements were performed by means of two ASD FieldSpec in coincidence of CHRIS/Proba acquisitions. Two bare soil surfaces representing bright and dark soil conditions and one alfalfa field were selected for the spectral profile measurements.

Table 1. Acquisition geometry for SPARC2003 (F.Z.A.: Flight-by Zenith Angle)

F.Z.A.	+55	+36	0	-36	-55
12/07/2003					
Azimuth	26.11	37.98	102.40	165.44	177.06
Zenith	55.99	38.78	19.40	39.15	56.24
14/07/2003					
Azimuth	353.77	339.44	285.27	231.22	216.91
Zenith	57.29	42.44	27.6	42.53	57.40

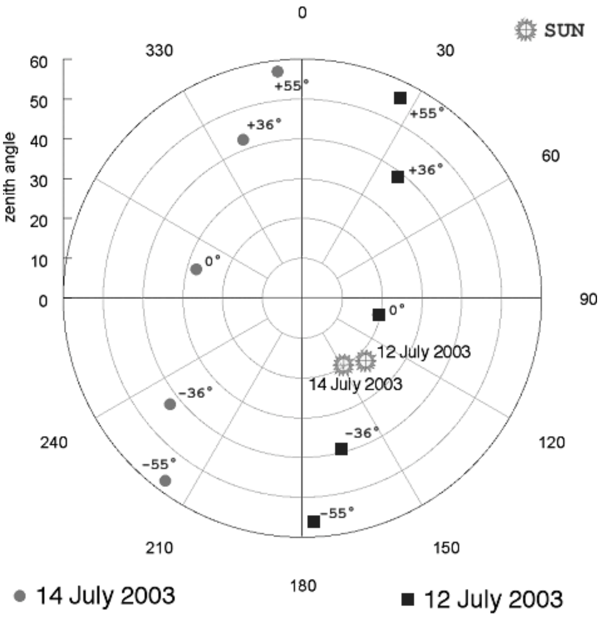

Fig. 2. Sampling geometry of the BRDF data

2.4 Radiative transfer models

In order to compare CHRIS/Proba BRDF data with simulated BRDF from a radiative transfer model we have chosen SAILH (with the Hotspot effect) [9] [10] [11] for the description of the canopy radiation fluxes and PROSPECT [12] [13] for the simulation of the leaf optical properties (Fig. 3).

Two fundamental criteria have led us to choose PROSPECT+SAILH model: i) simplicity, i.e. the possibility to have a rather good representation of the radiative transfer of the canopy using a relatively small amount of input parameters as well as limited computational requirements, and ii) reliability since the SAILH model has been successfully tested for a large set of crops, among which corn [14] and sugar beet [15], which were present in our study-area.

In order to simulate top of the canopy reflectance by PROSPECT and SAILH models, 7 vegetation

Table 2. Key characteristics of CHRIS/Proba

Spatial sampling	18 m on ground at nadir
interval	
Image area	14 km X 14 km (748 X 748 pixels)
Spectral range	410nm to 1050 nm
Number of spectral bands	63 bands at a spatial resolution of 36m
Spectral resolution	1.3 nm @ 410nm to 12 nm @ 1050nm (i.e it varies across the spectrum)

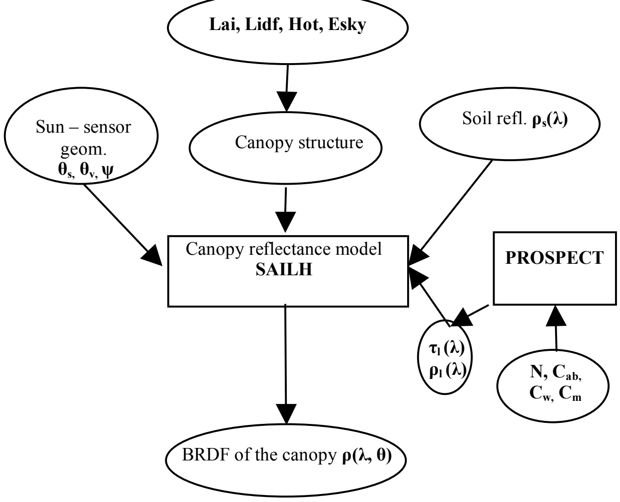

Fig. 3. Basic flow-chart of the combined used of PROSPECT + SAILH models.

parameters, 3 sun-sensor geometric parameters and 1 visibility parameter are needed to calculate the BRF for each wavelength and for each view angle for a given sun-sensor geometry. Thus:

$$\rho(\lambda,\theta_v) = f(N, C_{ab},C_w,C_m, LAI, HOT, LIDF,\theta_s,\psi,Esky) \quad (1)$$

where:

$\rho(\lambda,\theta_v)$ = canopy reflectance at wavelength λ and view zenith angle θ_v
N = Leaf mesophyll parameter
C_{ab} = Chlorophyll a and b content
C_w = Water content
LAI = Leaf area index
HOT = Hot spot parameter
LIDF = Leaf inclination density function
θ_s = Sun zenith angle
ψ = Relative sun–object azimuth angle
Esky = Diffuse part of the incoming radiation

The hot spot parameter HOT is defined as the ratio between the average size of the leaf and the canopy height [10].

A first validation of the PROSPECT and SAILH models on the test-site was performed by using the spectral measurements done on the alfalfa field with the ASD FieldSpec instrument. The following input parameters were considered: nadir view, C_{ab}=50 mg/cm^2, C_w=0.011 g/cm^2 C_m=0.0055 g/cm^2, LAI=2.7, HOT=0.057 and Esky=0.13, as from ground measurements, while we have assumed N=1.8 [19] and Spherical LIDF (average leaf angle 57°). The PROSPECT+SAILH models were then run with 9 different background measured spectra, ranging from very bright to very dark. The maximum radiometric discrepancy due to the soil background effect was evaluated around 13.7% (VIS=14.4%; NIR=12.9%). Fig. 4 shows that the best fit between simulated and measured alfalfa canopy reflectance spectrum, which was obtained by choosing a wet (dark) soil. The value of RMSE = 2.298 over all wavelengths was considered satisfactory.

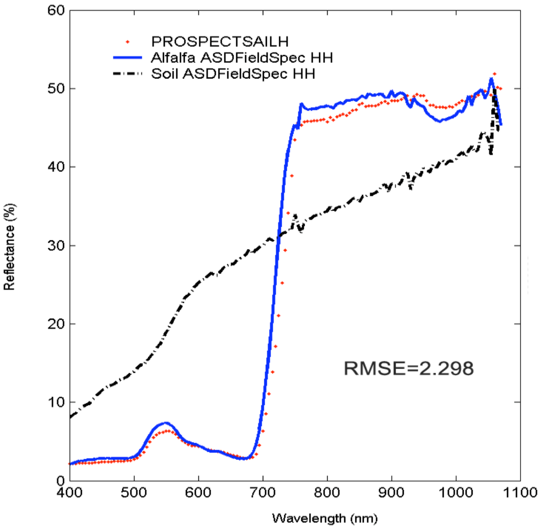

Fig. 4. ASD FieldSpec- measured vs. simulated spectra for a Alfalfa field

3. INVERSION ALGORITHMS

Two algorithms were considered to solve the inverse problem: i) the construction of LookUp Table (LUT) and subsequent best-fit procedure, and ii) the PEST-ASP software tool [16], based on the Gauss-Marquardt-Levenberg algorithm.

3.1 LookUp Table

The LUT is a very easy to implement method consisting in the following steps:

- sampling the parameters space of canopy for a given sun-sensor geometry;
- for each combination of canopy parameters, computing and storing the spectral profile generated by means of PROSPECT and SAILH models;
- finding which set of canopy parameters corresponds to the best fit between observed and simulated spectral profile, according to the minimum RRMSE defined as:

$$RRMSE = \frac{RMSE * \sqrt{n_i n_j}}{\sqrt{\sum_{j=1}^{n_j=5}\sum_{i=1}^{n_i=62}\left[\rho_{measured}(j,i)\right]^2}} = \sqrt{\frac{\sum_{j=1}^{n_j=5}\sum_{i=1}^{n_i=62}\left[\rho_{measured}(j,i) - \rho_{estimated}(j,i)\right]^2}{\sum_{j=1}^{n_j=5}\sum_{i=1}^{n_i=62}\left[\rho_{measured}(j,i)\right]^2}} \quad (2)$$

where:

$\rho_{measured}$ (j,i)= Observed reflectance in the jth view angle, ith band

$\rho_{estimated}$ (j,i)= Simulated reflectance in the jth view angle, ith band

The main advantage of the LUT is that the forwarding modelling process is disjointed by the inversion procedure. Hence, the simulated spectral firms have to be computed only once.

In this study, no particular distribution function for the vegetation parameters was assumed in order to sample the parameters space. They were sampled uniformly according to Table 3. C_w was fixed since the leaf water content doesn't affect the spectrum in the 400÷1000 nm range and 5 different leaf inclination distribution, corresponding to 5 different plant architecture (Planophile, Plagiophile, Extremophile, Erectophile, Spherical) were taken into consideration. Finally, the sun-sensor geometric parameters were set according to CHRIS/Proba pass 12/7 (Table 1). The Esky parameter was retrieved through the atmospheric measures.

A total of 585000 simulated spectra were thus computed.

3.2 PEST- ASP© tool

The model independent Parameter Estimation program PEST [16] is used to determine the optimised parameters accordingly to a pre-defined cost-function. PEST is a nonlinear parameter estimation program, which can be easily linked by templates to any model. It runs the specific model, compares the model results with the observed (measured) values and adjusts selected parameters using Marquardt-Levenberg optimisation algorithm [17], [18]. The procedure is iteratively repeated until the optimal set of adjustable parameters (Fig. 5).

4. RESULTS AND DISCUSSION

Table 3. LUT parameters and space

Parameter	Range	Increments	# of samples
N	[1.5,2.5]	0.2	6
C_{ab}	[10.70]	5	13
C_w	0.011		1
C_m	[0.002,0.02]	0.002	10
LAI	[1,6.8]	0.2	30
HOT	[0.05,05]	0.1	5
LIDF	5		5
Esky	0.13		1

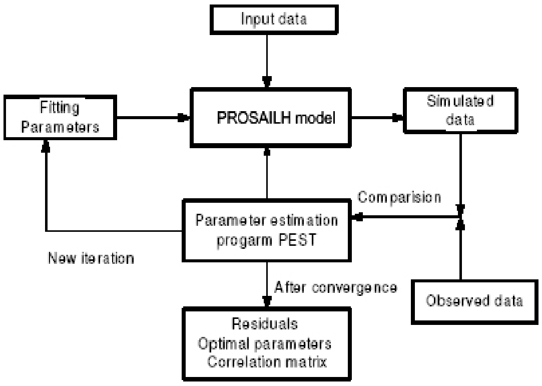

Fig. 5. ASP-PEST routine

The multi-angular surface reflectance data were extracted from the atmospherically corrected image acquired by CHRIS/Proba on July 12th. The overlay area for the images on all five angles (-55°, -36°, 0°, +36°, +55°) included 39 fields were LAI measurements were taken on 5 different types of crop (Alfalfa, Potatoes, Sugar Beet, Corn, Onion).

The BRDF of these 39 plots were extracted from the CHRIS/Proba images by taking the mean reflectance value at each angle in a window of 3x3 pixels.

In order to characterise the average soil surface reflectance, we extracted 50 different bare soil spectra from the nadir image and we calculated the average. In Fig.6, the mean and the extreme spectral values for the bare soil surfaces observed in the nadir image are shown. We may notice that the average soil spectrum resulted similar to one collected at ground by means of ASD FieldSpec, which was finally chosen to represent the soil reflectance in the application of SAILH model. To this end, we considered the soil background contribution as a constant within the whole image, beside the assumption of Lambertian reflection.

In a first step of the inversion process based on the LUT approach, we tried to retrieve LAI for all 5 crops without applying any *a-priori* knowledge, i.e. no restrictions were considered in the range of variability

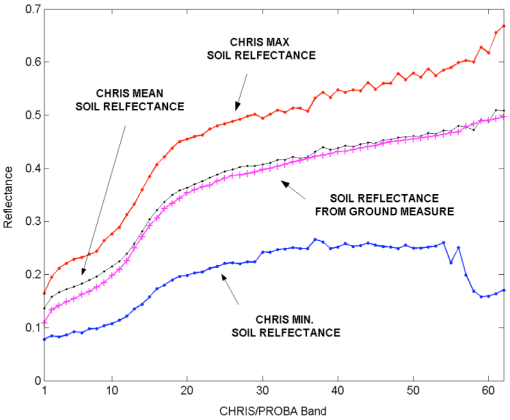

Fig. 6. Different reflectance spectra from CHRIS/Proba and ASD FieldSpec measures

of input parameters. In such case, the total RMSE between estimated and measured LAI values was found to be equal to 2.1. Considering a crop-by-crop analysis the RMSE value for Alfalfa dropped to 0.26, probably due, in this case, to a better correspondence to the turbid medium assumption of the SAILH model; the worst results were obtained for the potatoes, which LAI values resulted to be constantly underestimated by around 40%. Rather poor estimations results were obtained for the other crop types. In this inversion procedure based on the PEST-ASP tool on the same fields of the LUT approach, we could achieve a better RMSE=1.56. Then, we focused on the three main crops of our study-area: alfalfa, potatoes and sugar beet. In order to increase the accuracy of the inversion procedure, we applied some restrictions to the parameter variability, based on the knowledge of the crop type. At first instance, we limited the range of variability of input parameters; successively, we fixed one or more parameters values. This a-priori knowledge can be easily introduced in the inversion process performed by means of PEST-ASP tool. For all the inversions we fixed, beyond sun-sensor geometrical parameters, the water content, since its effect on the overall reflectance in the range of frequencies 400÷1000 nm should be negligible, Esky as given by the atmospheric measures, and the LIDF as closest as possible to the geometrical canopy structure. In the case of alfalfa, the remaining five parameters were bounded to the following ranges: $1<N<2$, $10<C_{ab}<110$, $0.001<C_m<0.02$, $0.0001<HOT<1$, and $0.3<LAI<8$. This strategy proved to be very effective, resulting in a RMSE of 0.3 in the retrieval of LAI. Similar procedure was followed in the case of potatoes fields, by limiting the range of N to the interval 1÷1.6. The valued of RMSE= 0.4 was obtained in this latter case.

Finally, we tried the inversion procedure on sugar beet fields. The leaf structure parameter N was fixed to 1.5, as it was found in literature [15], and the mean leaf inclination fixed to 65° [20]. Although the canopy of this crop strongly departs from the turbid medium hypothesis of SAILH, the strategy of applying *a-priori* knowledge produced a good agreement between LAI field measurements and LAI estimated, with a RMSE = 0.49. On all the three crop types considered, the overall RMSE in the estimation of LAI parameter was thus 0.42 (Fig. 7)

5. CONCLUSIONS

A preliminary analysis on CHRIS/Proba data has been carried out in this study with the purpose of LAI estimation for agricultural crops. The spectral and spatial information content of the satellite data was exploited to validate canopy reflectance models. It has been demonstrated the effectiveness of the combined use of PROSPECT and SAILH models to simulate canopy BRDF of alfalfa and potatoes crops with a good accuracy (RMSE of 0.3 and 0.4 respectively).

A first attempt of inversion has been carried out using all the information available from hyper-spectral and multi-angular CHRIS/Proba data. The retrieved LAI parameter was estimated with an accuracy of around 15%÷20% for most of the samples.

The investigation has also shown the importance of the soil component in the overall image reflectance. Therefore a better vegetation parameters estimation can be achieved using either a soil spectral map of the image or, more reasonably, a soil BRDF model which takes into account chemical, physical and geometrical soil parameters removing, thus, the Lambertian surface hypothesis.

The results obtained for the crops under investigation encourage to the use of canopy reflectance models in the inverse mode in order to retrieve also other vegetation parameters such as chlorophyll content, dry matter and canopy geometrical characteristics like mean leaf inclination angle. Further steps in the inversion process of hyper-spectral and multi-angular data will be the use of semi empirical models for a first attempt of vegetation parameter estimation to better solve the ill posed problem adding more a priori knowledge. An analysis of the redundancy of information in both the spectral and angular domain will be also performed.

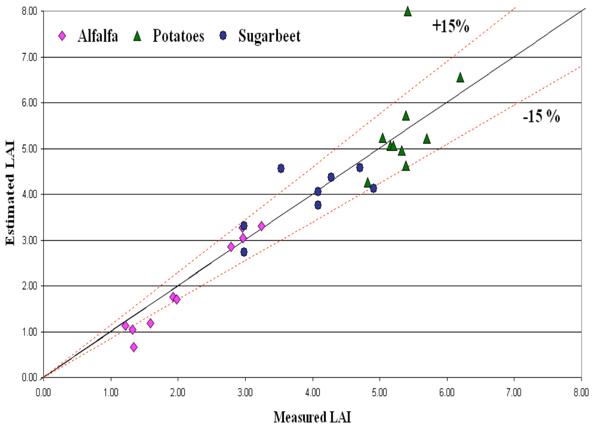

Fig. 7. Estimated vs. in situ LAI measurements for Alfalfa, Potatoes and Sugar Beet.

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